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Comparative Study of Cardioplegia by Anoxic Arrest and Elective Fibrillation under Extracorporeal Circulation Using Left Ventricular Function Curve

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I. Introduction

In open heart surgery, cardiac cooling methods including the use of cardioplegic solution and topical cooling are commonly used to protect myocardium during a long period of cardiac arrest.

However, for short duration operations in such cases as atrial septal defect, ventricular septal defect, and pulmonary stenosis, either anoxic arrest or electric fibrillation is used. One crucial point in cardioplegia is to sustain myocardial viability as much as possible during the period of cardiac arrest. Therefore, to investigate the feasibility of these anoxic arrest and electric fibrillation methods for the potential clinical application, the author examine the change in cardiac functions before and after cardiac arrest. The comparative study was made with the Sarnoff's cardiac function curves under the extracorporeal circulation. Prior to the experiment, only extracorporeal circulation was initiated, without cardiac arrest, to investigate its effects on cardiac functions.

II. Materials and Methods

Mongrel dogs were anesthetized with sodium pentobarbital injected through a vein, and a Bird Respirator was applied to mechanically maintain respiratory function. Thoracotomy was performed at the 4th right intercostal space. Two tubes were inserted through the right atrium: one into superior vena cava and the other, into inferior for blood withdrawal and then another one, into the right femoral artery for blood pumping. The former two of these tubes were coupled by a Y-tube and then connected to a Dabilla-Pemco Heart-Lung Unit. When measuring stroke work of the left ventricle, the blood pumping channel through the femoral artery was blocked. Instead, blood was transfered only through the right atrium, allowing blood from both venae cava to flow into the right atrium (Figure 1).

The cardiac stroke work is determined by the left atrial pressure, the femoral artery pressure,

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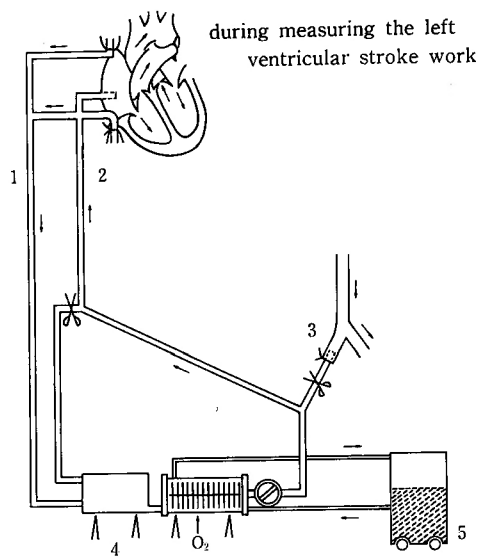


Fig. 1.

1. venous return through the superior and inferior vena cava
2. arterial perfusion through the right atrium
3. femoral artery
4. reservoir
5. heat exchanger

and heart beat, all of which are affected by the flow volume of blood, according to the equation: ventricle stroke work=

$$\frac{\text{cardiac output cc/m (arterial pressure cm}H_2O\text{-left atrial pressure cm}H_2O)}{100\times\text{pulse/m}}$$

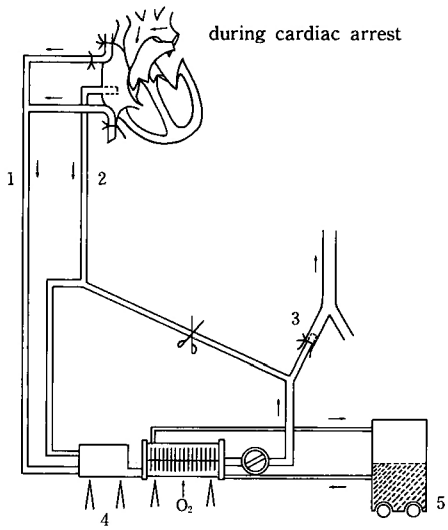
Therefore, in the Sarnoff's[2] cardiac function curve, the horizontal axis represents atrial pressure and the vertical axis, cardiac stroke work. In other common cases of extracorporeal circulation where the blood channel to the right atrium is blocked, only the channel to femoral artery is used. Blood withdrawn from both venae cava is transmitted after being oxygenated in the artificial lungs (Figure 2).

To examine the changes in cardiac function, 120-minute extracorporeal circulation was initiated and cardiac function curves were drawn before and every 30 minutes during circulation.

Cardiac function curves were classified into 4 grades according to the Race[1] classification method. They were ranked from N, 1, 2, to 3, as shown in (Figure 3).

Experiments

For measuring the initial cardiac stroke work of the left ventricle, the same procedures as those for preliminary experiment were used. Heart was arrested intentionally and 15 minutes later, it was resuscitated. After 15 and 30 minutes of extracorporeal circulation, the first and the second cardiac function curves were drawn, respectively, to observe the lowering of the function and its recovery.



extracorporeal circulation through the femoral artery

Fig. 2.

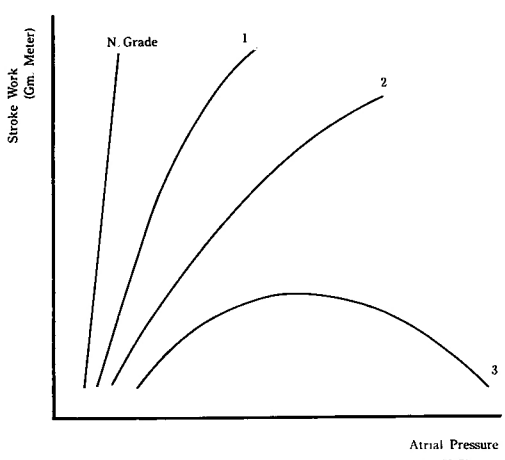
2. return of the coronary sinus blood through the atrium
1. 3. 4. 5. same as in Fig. 1.

For the cardiac arrest, the 3 following methods were used.

1. Anoxic arrest

The aorta was constricted with tape encompassing the ascending aorta.

2. Electric fibrillation
3. Combined method of electric fibrillation and aortic clamping



Classification of Ventricular Function Curve (Rase)

Fig. 3.

An alternating current (7–10 V) was applied to the both ventricles for about 0.5 seconds to generate fibrillation and after 15 minutes of fibrillation, they were defibrillated with a current (150–180 V) and 0.1 second counter shock.

3. Electric fibrillation and aorta blocking

Electric fibrillation was induced according to the procedure of the second method and immediately the aorta was constricted with tape. When fibrillation occurred during the process of resusciation, counter shock was applied.

III. Results and Conclusion

1. The results of the preliminary experiment and the 5 cardiac function curves demonstrated significant difference in cardiac stroke work among the 5 cases but the rates of increase in cardiac stroke work were almost identical to each other, indicating good recovery of function. Since the activity of cardiac function may be expressed by the increased ratio of cardiac stroke work to an increase in atrial pressure rather than by the volume itself, the sharp increment in these

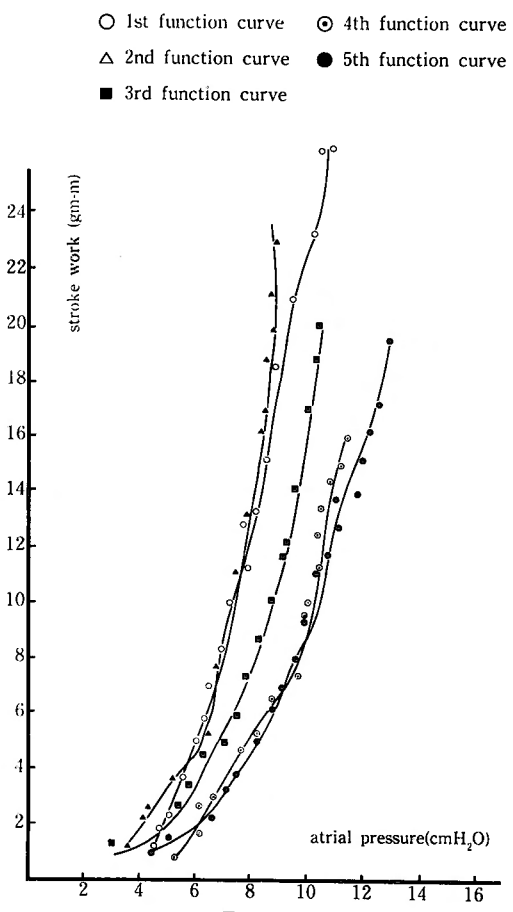


Fig. 4.

5 curves suggests the normal cardiac function (Figure 4).

To investigate the effects of extracorporcal circulation on cardiac function and eliminate them prior to a comparative study of cardiac arrest methods, the author conducted extracorporeal circulation for 120 minutes. The results indicated, however, the circulation had no serious effects on cardiac function. With the 30-minute circulation, 4 out of 5 cases were normal and one showed Grades N-1 of decrease; with 60 minutes, one case was normal and 4 cases showed Grades N-1, with no significant decrease in the function at the end of the circulation. Thus, it was concluded that the effects of extracorporeal circulation were negligible in the comparative study of cardiac arrest methods because the experiment was completed within 60 minutes.

2. Results of main experiment and discussion

With the anoxic arrest method, cardiac functions were well maintained after cardiac arrest and also good recovery of the function was observed.

In the initial cardiac function curves, drawn after the 15-minute extracorporeal circulation following anoxic arrest, 4 out of 6 cases were normal and 2 cases showed Grades N-1 of decrease (Figure 5).

Thus, with the advantages in terms of good maintenance of cardiac function, simplicity and safety, this may be a good method especially for short operations. However the disadvantages of this method are the long time necessary for cardiac arrest and for recovery, and the difficulty

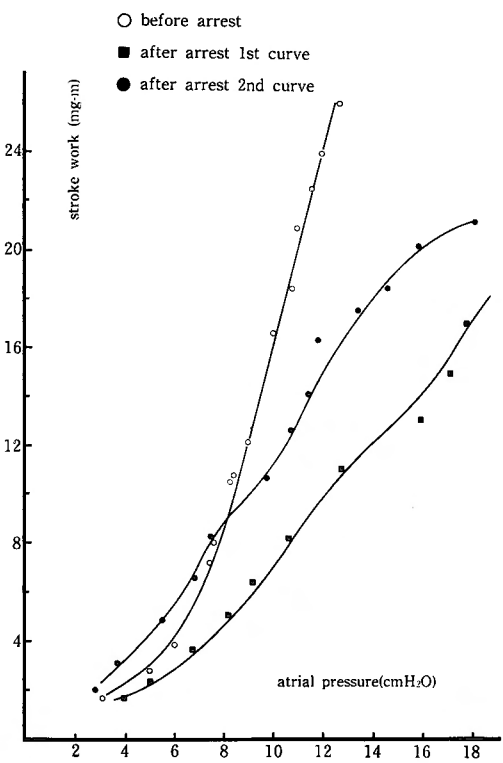


Fig. 5.

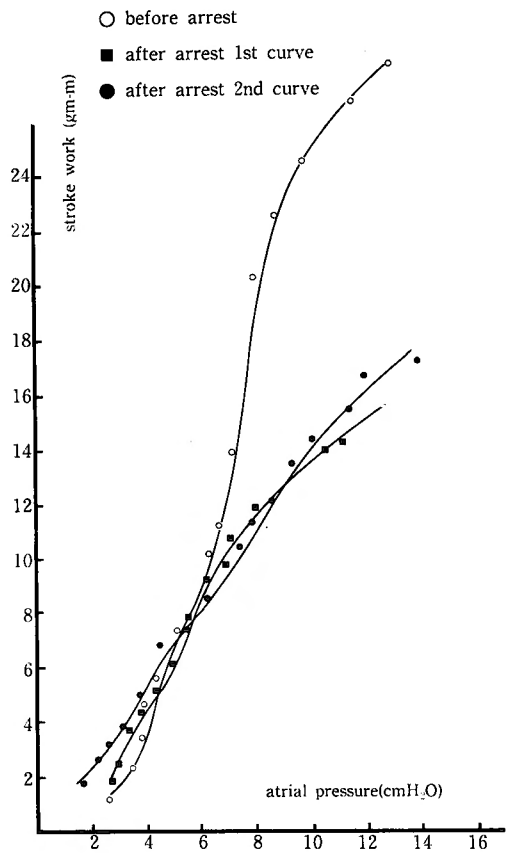


Fig. 6.

in achieving complete cardiac arrest, which increases the risk of air embolus.

With the electric fibrillation method, cardiac functions decreased the least, as exemplified by 3 normal cases and 2 cases of Grades N-1 (Figure 6). In addition, the other advantages were the shortest recovery time (within 1 min.), only slight electrocardiographic changes, simplicity and promptness in fibrillation and defibrillation, with little risk of air embolus. The one draw back of this method is, however, that there is no bloodless region during operation because the coronary circulation is maintained even during the fibrillation. Although it may be possible to develope a bloodless region by generating fibrillation and blocking the aorta at the same time, 15-minute synchronous performance of electric fibrillation and aorta blocking caused significant decrease in cardiac function. The initial cardiac function curve drawn after the cardiac arrest showed one case with Grades N-1, 2 cases with Grade 1, and 1 cases with Grades 1-2 (Figure 7). Therefore, it is suggested that aorta blocking be performed only for a short duration.

Conclusion

A study was conducted on the effects of cardiac arrest on cardiac functions by means of anoxic arrest and electric fibrillation under conditions using pump-oxygenator and extracorporeal

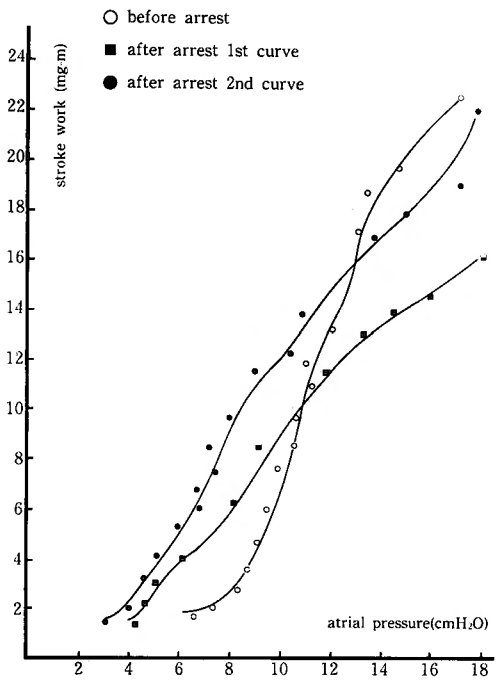


Fig. 7.

circulation. The results were examined on the basis of the Sarnoff's cardiac function curves.

1. Thirty-minute application of the pump-oxygenator had no effect on cardiac functions.
2. Neither electric fibrillation nor anoxic arrest caused a significant change in cardiac functions.
3. Synchronous performance of electric fibrillation and aorta blocking had significant effects on cardiac functions.
4. For a short-duration cardiac arrest in open heart surgery, it may be advisible to use either electric fibrillation, anoxic arrest, or a combined method of electric fibrillation and aorta blocking depending on the cases.

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和文抄録

体外循環における大動脈遮断法と電気的細動法による心停止法の実験的比較検討
―特に心機能曲線を中心として―

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我々は犬の実験において，Sarnoff の方法を体外循環に応用し，心停止前後の心機能曲線を描き，最も簡単で，短時間の心停止に用いられる anoxic arrest と電気細動法それにこの2つの合併法の3つの方法の心機能に及ぼす影響を比較検討した．また体外循環そのものの心機能に及ぼす影響を知るために，心停止を行なわず，体外循環のみを行い，心機能曲線の経時的変化を追求し，予備実験とした．その結果，30分の体外循環は心機能への影響はなく，anoxic arrest と電気細動法は，同じ程度に心機能低下は少く，両者の併用法は意外と心機能低下をきたすことが解った．